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Title:	Thermal Analysis and Flowability of Biomass Feedstock
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Rheological Characterization of Biomass Feedstock for Alternative Energy Applications

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Background: Introduction to Bulk Solids

- What are bulk solids?
  Loose solid material, e.g. sugar, salt, coal powder, ground corn stover.

Biomass → Reusable Material

- What is biomass feedstock?
  Organic wastes, agriculture residues that can be sustainable for reusable material.

- What is a biorefinery?
  Converts biomass feedstock to useful fuels and chemicals

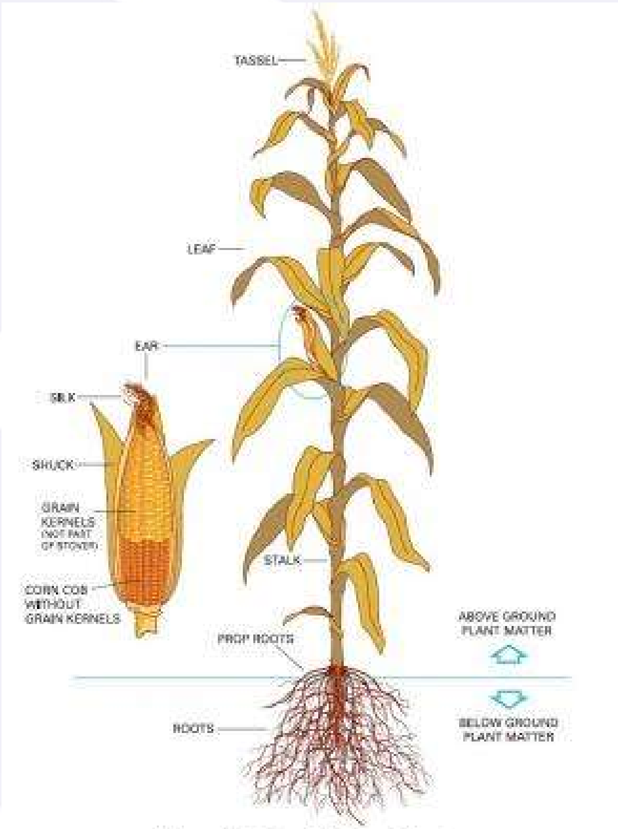


Figure 1: Parts of a Corn Plant

Corn Stover

K Arora M Licht k leibold "Industrial Corn Stover Harvest." Iowa State University, March 2014

Objectives

Short-term:

- Characterize the flow behavior of corn stover bulk solids with different moisture contents

Long-term:

- Use the measured flow behavior to re-design storage/handling equipment to mitigate the impact of moisture

Challenges

Flowability:

- Dependent on many environmental factors
- Particle size/geometry
- Variability in biomass feedstock (moisture content, chemical composition, storage conditions, etc.)

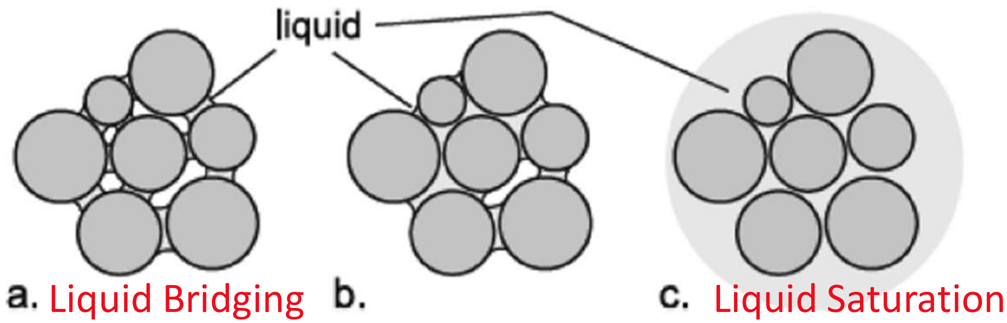
Problem with Moisture:

- Clogging of the processing/handling equipment
- Long down-time, high operational cost

How do we maximize flowability to transport bulk solids?

Need to characterize the flow (rheological) behavior as a function of moisture content

Flowability vs Moisture Content



What percentage of moisture yields the greatest flowability in bulk solids?

Low liquid lubrication → High particle cohesion/Surface tension → Decreased flowability

High liquid lubrication → Suspension/Low surface tension → Increased flowability

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Image: Cheng, Z. et al. *Powder Technology*, 1 Apr. 2021, pp. 157–180.

Experimental Methods

Sample Information:

- Low ash corn stover, ground to 2 mm in diameter
- Moisture: manually add DI water to corn stover
- % Moisture content=mass of water/total mass

Instrument: Freeman Technology Powder Rheometer

Powder rheometer

Shear cell

Stirring blade

Compression piston

Images: Courtesy of Freeman Technology Ltd.

Experimental Methods

I. Stability and Variable Flow Rate Test

Procedure

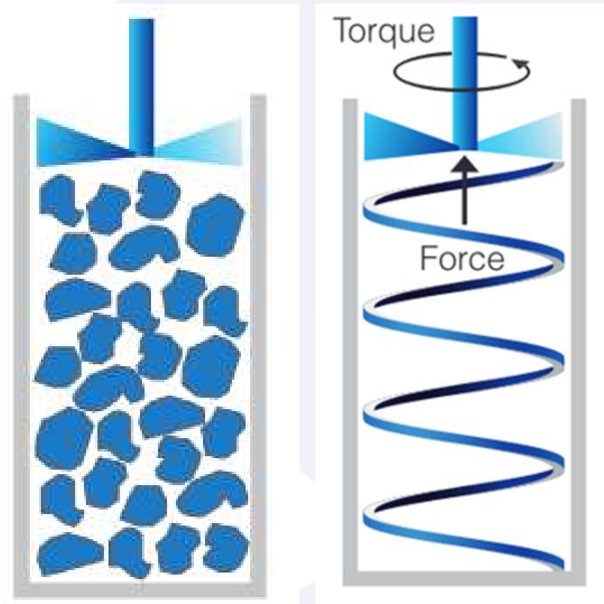
- 11 alternating conditioning/testing cycles with variable blade speed
- Tests 1~8: 100 mm/s
- Test 9, 10, 11: 70, 40 and 10 mm/s

Measurements

- Flow energy (mJ): measurement of amount of work required to move blade though powder
- Basic flowability energy=flow energy of Test 7

Purpose

- Access the stability in flow energy: tests 1~8
- Access the dependence of flow energy on blade speed: tests 8~11



Images: Courtesy of Freeman Technology Ltd.

Experimental Methods

II. Compressibility Test

Procedure

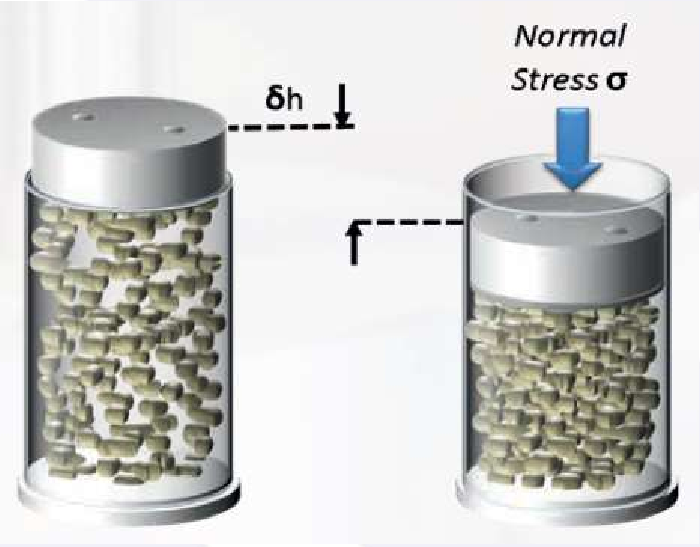
- 1 conditioning cycle
- Increasing normal stresses are applied

Measurement

$$\% \, Compressibility = \frac{V_0 - V}{V} \times 100\%$$

Purpose

Obtain % compressibility vs. applied normal stress



Images: Courtesy of Freeman Technology Ltd.

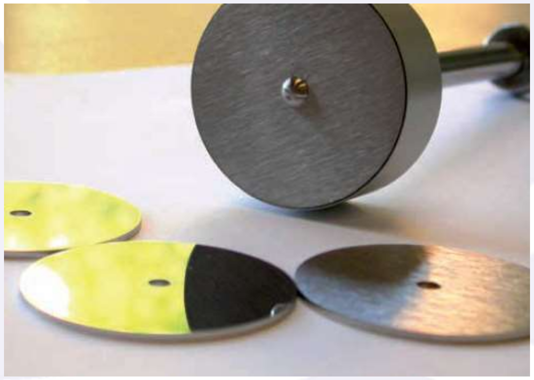
Experimental Methods

III. Wall Friction Test

- Procedure
  - Conditioning Cycle
  - Sample Compression
  - Normal stress is applied with rotation (shearing) disks
  - Materials tested: Stainless steel, PTFE

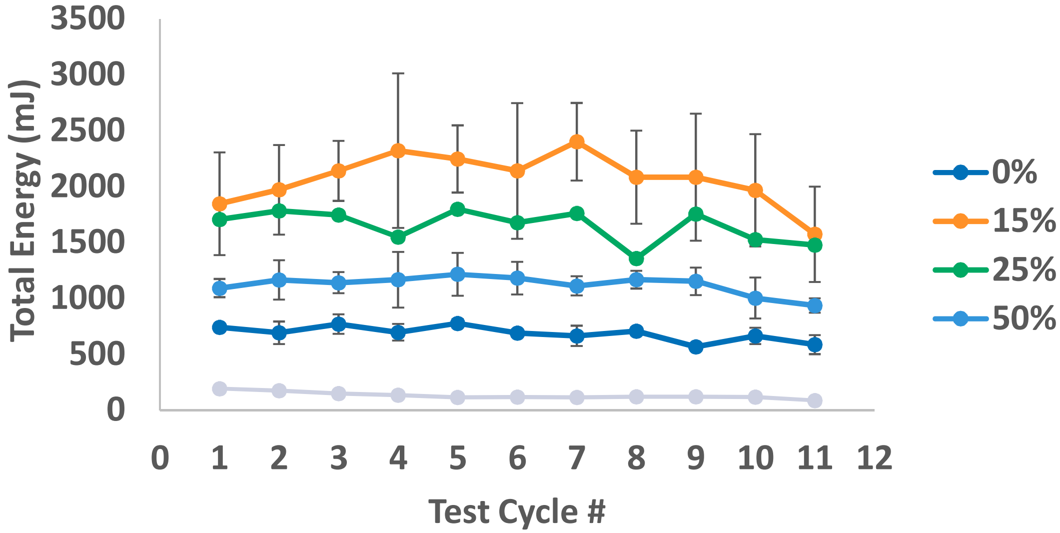
- Measurements
  - Wall friction angle: amount of friction/resistance against material.

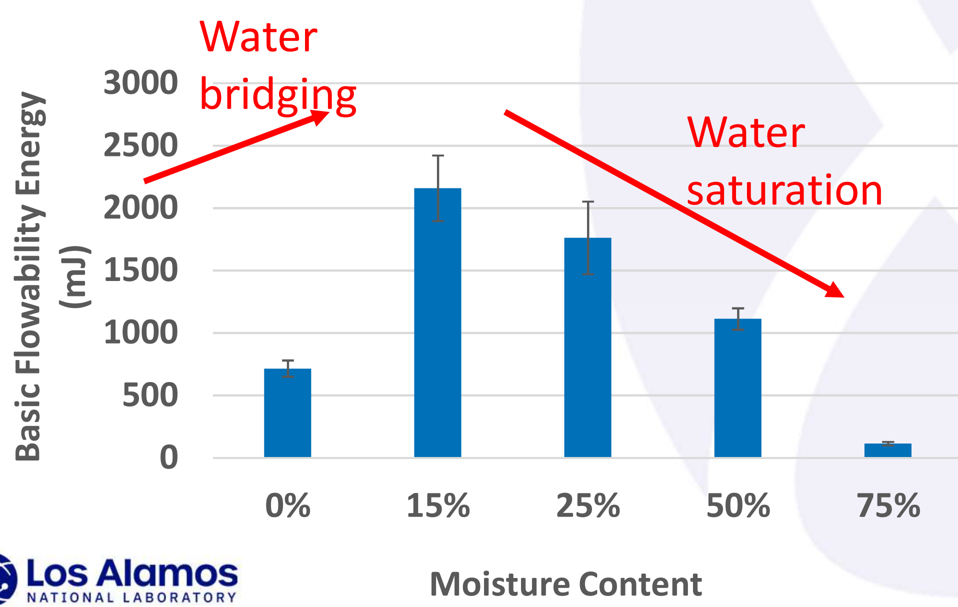
- Purpose
  - What material causes the least amount of friction between corn stover and transport material?



Images: Courtesy of Freeman Technology Ltd.

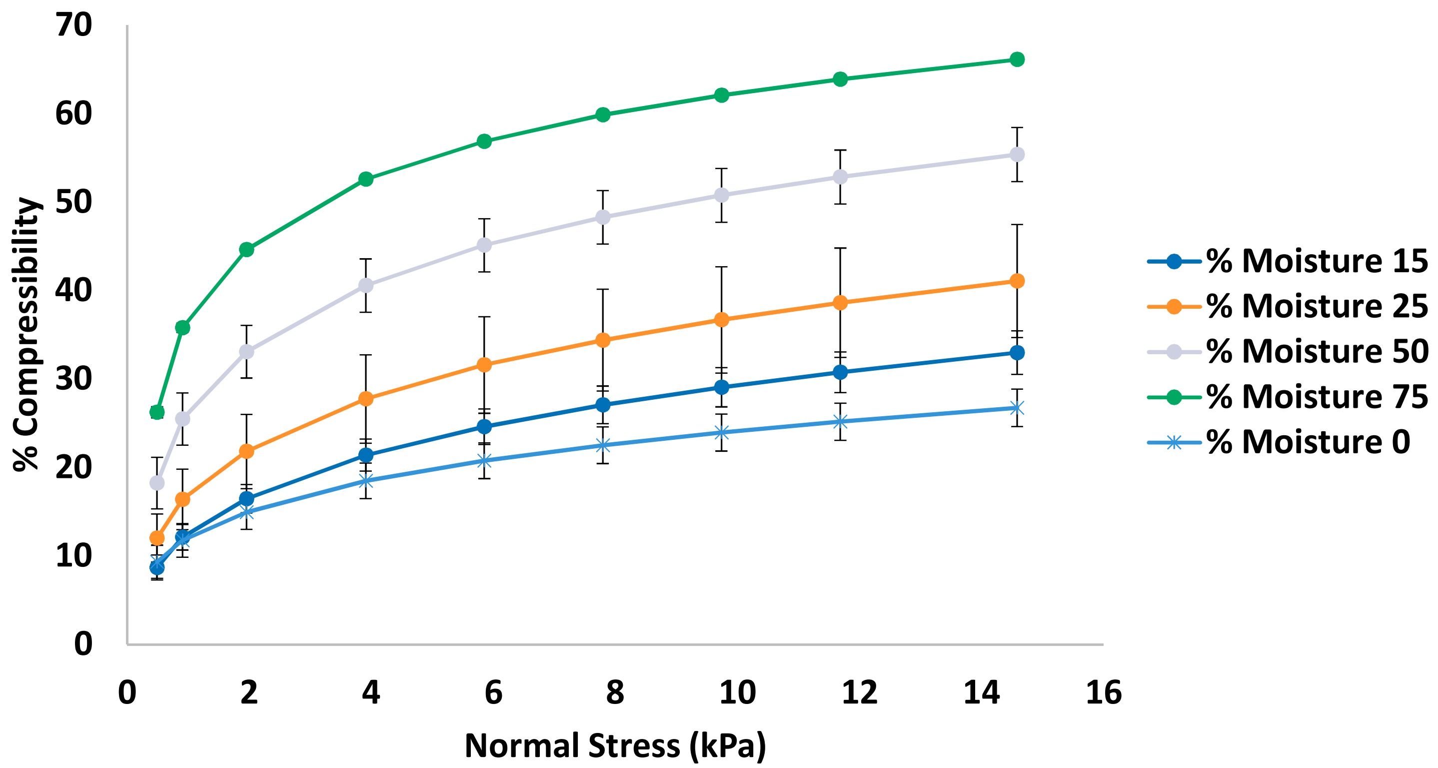
Stability & Variable Flow Rate Test





- 0%~15% moisture: increasing amount of energy needed to turn the blade
- 15% moisture: maximum BFE
- 15% ~75% moisture: decreasing amount of energy needed to turn the blade

Compressibility Test



- As normal stress increases, compressibility increases, and at a slower rate.
- Greater moisture content → greater compressibility
- Larger clusters form with increasing moisture→ looser packing

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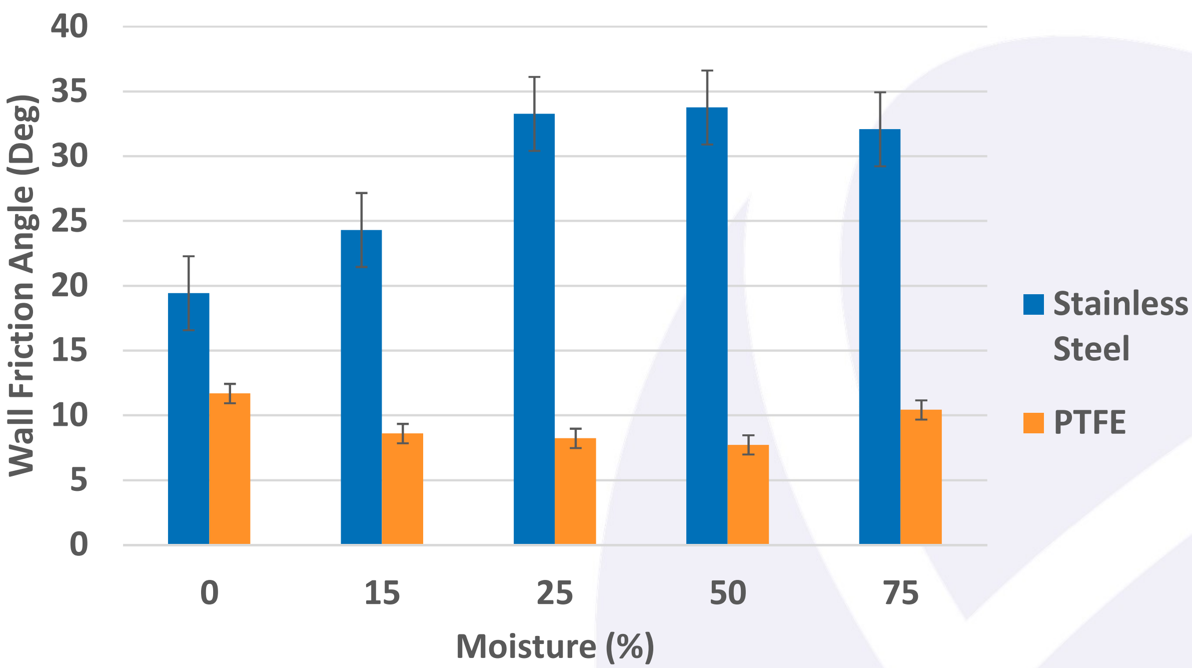
Wall Friction Test



- Stainless Steel Disk: Hydrophilic
- PTFE Disk: Hydrophobic

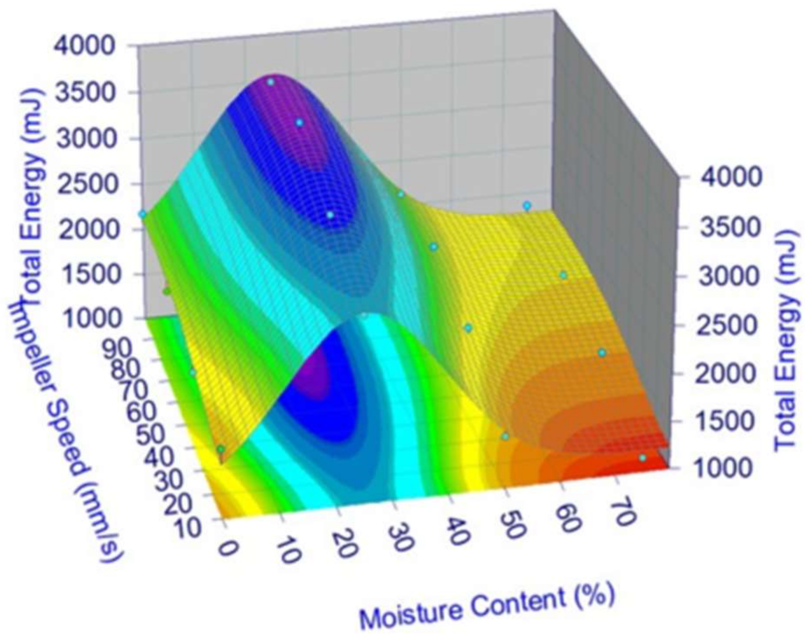
- Stainless Steel:

(1.2 um surface roughness) Wall friction first increases and then reaches a plateau when exposed to 25% or greater moisture.

- PTFE: (Polytetrafluoroethylene):

wall friction first decreases, plateaus after 15% moisture, and increases at 75% moisture exposure.

Summary and Conclusions



3D plot for the stability and variable flow rate test

- Based on the stability and variable flow rate test, the best and worst moisture content is 75% and 15%, respectively.
- The compressibility continuously increases with moisture content
- The relationship between wall friction angle and moisture are different on hydrophilic (stainless steel) and hydrophobic (PTFE) surfaces
- The data collected in this study can help with designing handling/ processing equipment for continuous flow and improved process economics

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Images: Courtesy of Dr. Troy Semelsberger

Future Work

- **Compare chemical compositions and rheological properties of corn stover based on anatomical fraction.**

  How do the leaf, stalk and cob parts of the corn stover differ in terms of rheological properties?

- **Compare the rheological properties of high ash vs. low ash corn stover**

  How does high ash corn stover (biomass with high inorganic salt content) differ in rheological characterization and handling needs?

- **Use existing data for hopper design**

  Can we use existing handling equipment to economically transport and handle biomass feedstock?

Rheological data collected will be used in an upcoming publication

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